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Structural Performance of Nuclear Concrete Structures Affected by ASR

Briefing to the 28th Annual Regulatory Information Conference (RIC)

March 8, 2016

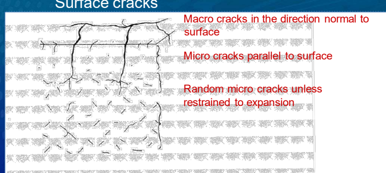
Fahim Sadek, H.S. Lew, and Sorin Marcu
Steve Feldman and Ken Snyder

NIST National Institute of Standards and Technology U.S. Department of Commerce

Materials and Structural Systems Division

Surface Cracking Due to ASR

Surface cracks



- **ASR** can occur over time between the highly alkaline cement paste and reactive poorly-crystalline or non-crystalline (amorphous) forms of silica found in many common aggregates.
- This reaction causes the expansion of the altered aggregate by the formation of a swelling alkali-silica gel.
- This gel increases in volume with water and exerts an expansive pressure inside the material, which may cause spalling and loss of strength of the concrete.

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Overall Study Objective and Outcomes

Objective:

To develop a technical basis and regulatory guidance for NRC to evaluate ASR-affected concrete structures.

The research will assess the structural performance of ASR-affected concrete structures for design basis static and dynamic loading and load combinations through its service life, including the period of extended operation for the 20 year license renewal period.

Outcomes:

A methodology to determine, for an existing ASR-affected structure;

- Current structural capacity to resist static and dynamic loads, and
- Estimate of future structural capacity to resist static and dynamic loads.

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Technical plan

Task 1: Assessing In-Situ Mechanical Properties of ASR-Affected Concrete

Task 2: Assessing Development and Lap-Splice Lengths of Reinforcing Bars in ASR-Affected Concrete

Task 3: Seismic Response Characteristics of ASR-Affected Concrete Structural Members

Task 4: Estimating the Degree of Reaction in ASR Affected Concrete and the Corresponding Expansion

Task 5: Predicting Future and Ultimate ASR Expansion in ASR-Affected Concrete

Task 6: ASR Effects on Transport of Ions through Concrete and its Potential for Causing Other Degradation Mechanisms in Concrete

Task 1: Assessing In-Situ Mechanical Properties of ASR-Affected Concrete

Objectives:

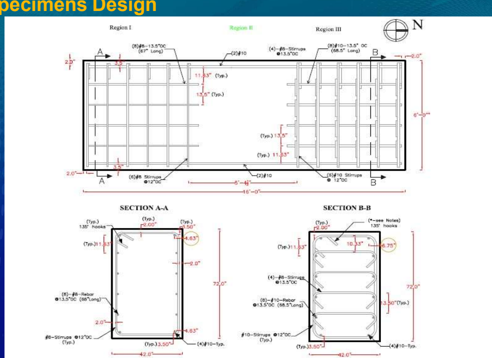
To establish:

- the relationship between expansion due to ASR and (1) concrete mechanical properties and (2) surface cracking of concrete, and
- the effectiveness of hoop reinforcement (i.e., stirrups) in confining expansion of concrete due to ASR.

Approach:

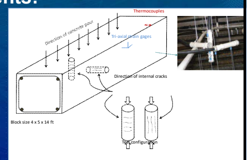
- Three large concrete block specimens made with known, natural reactive aggregates along with a control (non-reactive) block specimen will be cast. The three large block specimens will be fabricated with hoop stirrups placed at different spacings.
- Advanced computational modeling of the concrete blocks will be conducted to correlate the state of strain at the center of the block with surface cracking at various levels of reaction/expansion. The modeling results will be validated using measurements and observations from the test blocks.

Specimens Design

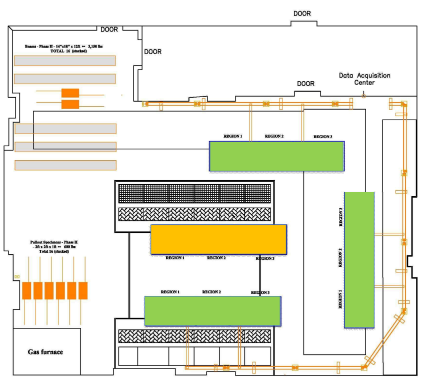


Instrumentation Plan

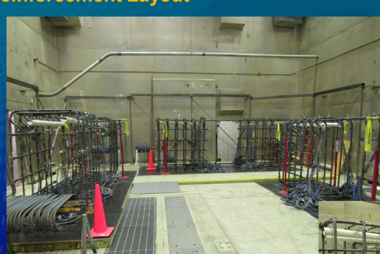
Strain Measurement Instruments:



- Core concrete strain measurement
  - Tri-axial transducers
- Concrete surface strain measurement
  - DEMAC (Demountable Mechanical) gauges
  - Laser tracking device
- Reinforcing bar strain measurement
  - Strain gauges



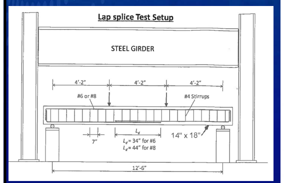
Reinforcement Layout

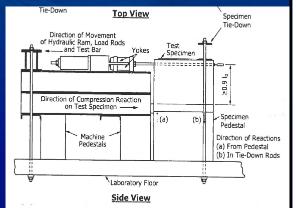


Task 2: Assessing Development and Lap-Splice Lengths of Reinforcing Bars in ASR-Affected Concrete

Objective:

To develop a methodology for assessing the effects of ASR on development length of steel reinforcement including (1) lap splices in flexural members, and (2) axially loaded reinforcing bars. The methodology will address the degree of loss of anchorage and flexural capacities.

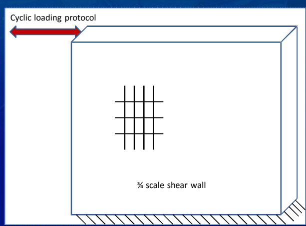




Task 3: Seismic Response Characteristics of ASR-Affected Concrete Structural Members

Objective:

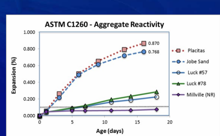
To develop a methodology for assessing the degradation of seismic resistance of structural members and systems due to ASR.



Expansive Mixture Design

Performance Criteria:

- 27 MPa (4000 psi)
- 10 cm to 15 cm slump (4 to 6 inches)
- Cement Content < 350 kg / m³ to limit exothermic heat of hydration
- Slump retention for approximately 1 hour
- Three levels of (ultimate) linear (unrestrained) expansion:
  - 0.15 %, 0.30 %, and 0.50 %
- Expansive natural aggregate: coarse & fine
  - Rhyolitic volcanic rocks and granite [alluvial gravel, coarse] – Bernalillo, NM
  - Low-grade metavolcanic rocks [crushed stone, coarse] – Rockville, VA
  - Mixed quartz / chert / feldspar [sand] – El Paso, TX



Range of aggregate expansion

Expansive Mixture Design

Technical Challenge:

- Target ultimate linear expansion to occur after 12 to 18 months
- Accelerated ASTM tests (C1260) are comparative tests
- Accelerated tests do not incorporate the 'as used' mixture design

NIST is using temperature to accelerate expansion in prisms using the target mixture designs.

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Task 4: Estimating the Degree of Reaction in ASR Affected Concrete and the Corresponding Expansion

Objective: Develop methodology for estimating the degree of internal expansion due to ASR

Approach:

- Relate the degree of internal expansion to the degree of reaction (DoR)
- Identify/Quantify reactive phases in the raw materials
- Identify/Quantify reactive phases in the hydrated materials
- Identify/Quantify reaction products in hydrated materials
- Validate a model to predict DoR from these quantities

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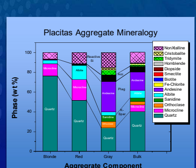
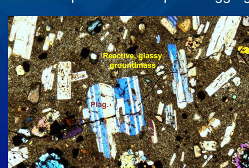
Expansive Mineral Phases:

- Methods are needed to quantify reactive phases in natural aggregates
- There are a large number of reactive crystalline and glassy phases
- Each aggregate type has different combinations of reactive phases
- The most effective measurement method depends on the specific aggregate





NIST is developing strategies for identifying and quantifying reactive phases in aggregates having different and highly complex types/combinations of reactive phases.

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Task 5: Predicting Future and Ultimate ASR Expansion in ASR-Affected Concrete

Objective: Develop test methods for predicting the future degree of ASR reaction in existing concrete structures

Approach:

- Develop an 'order of magnitude' model
- Primary factors: temperature, alkalinity, and aggregate volume fraction
- Develop and validate prediction model

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Task 6: ASR Effects on Transport of Ions through Concrete and its Potential Influence on Other Degradation Mechanisms

Objective: Develop a methodology for assessing the influence of ASR on the remaining service life of affected concrete

Approach:

- Use chloride ingress as a surrogate degradation mechanism
- Use non-expansive and expansive concrete mixtures
- Monitor chloride ingress and electrical resistivity of cracked samples
- Validate predicted changes in ingress to changes in resistivity
- Relative changes to rate of ingress gives relative changes to service life

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Questions?????

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